Service, Adoption & Maintenance

Ballard's Promise

November 2023

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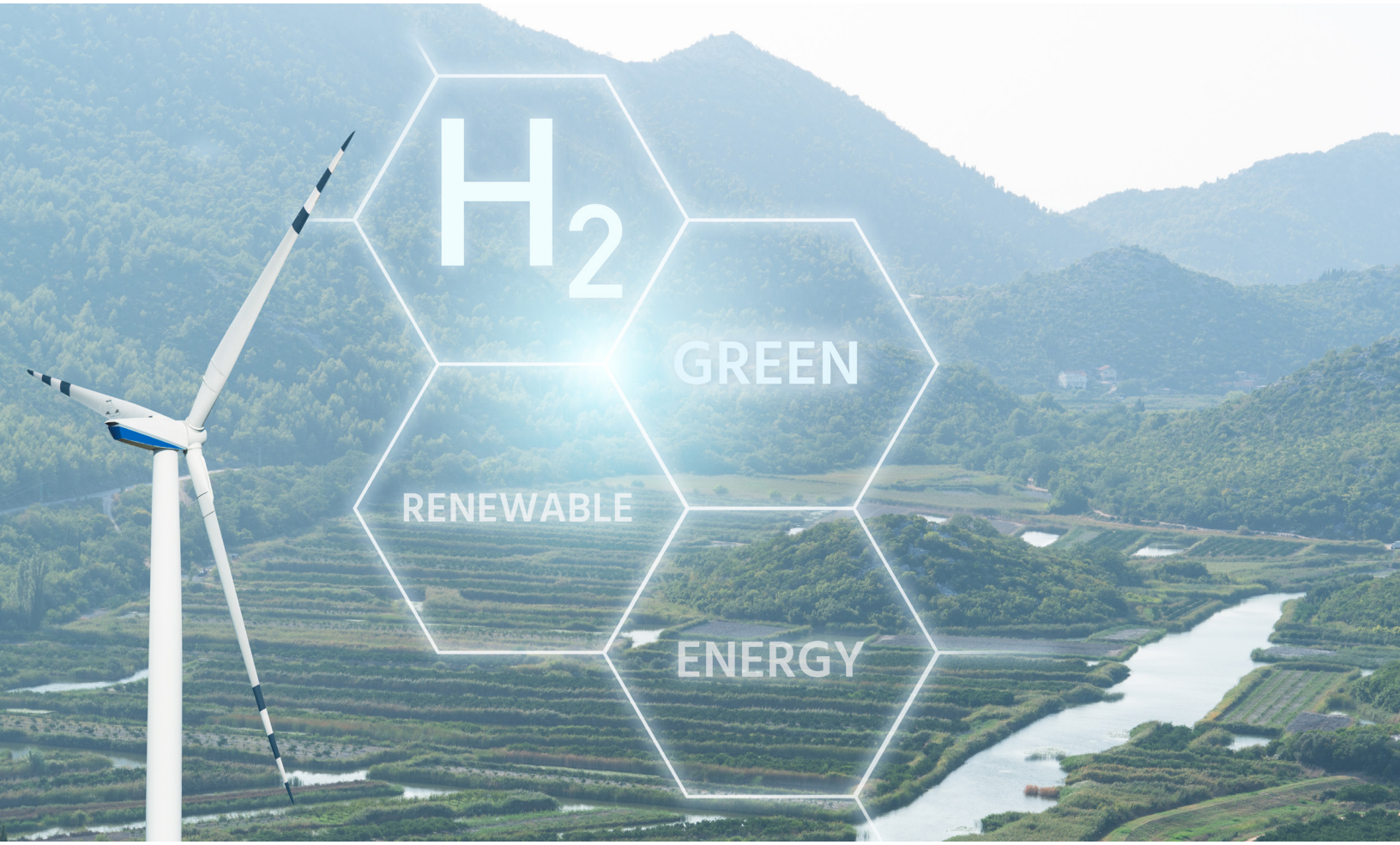
Introduction

Zero-emission technology is advancing all the time. New solutions, products and platforms are now in place to enable the global public transit bus industry to accelerate the adoption of decarbonization quickly, so that major players are establishing revized and enhanced practices, methods and infrastructure in order to safely and successfully transition towards zero-emission transit fleets.

Although the necessity and demand for zero-emission transit is at an all-time high, many transit operators are still unsure of how to make the transition or how to replace their existing infrastructure, especially when it comes to on-site bus maintenance facilities.

Upgrading vehicle maintenance facilities to safely accommodate hydrogen can be a deciding factor in whether an operator chooses to adopt this fuel for its fleet, and apprehension over hydrogen fuel safety represents a legitimate concern. There are inherent risks handling any flammable gas or liquid, including traditional gasoline or compressed natural gas (CNG). When used in accordance with proper guidelines, hydrogen fuel is safe for public transportation. Hydrogen has been used, transported, and stored safely in industrial applications for decades. Ballard-powered hydrogen-driven fuel cell electric buses have now traveled millions of kilometers in varied environments around the world, safely transporting thousands of passengers.

This paper reviews adoption, maintenance and best practices in hydrogen bus facilities for transit agencies. It includes safety and infrastructure factors transit managers must consider when transitioning to servicing and maintaining fuel cell electric buses.



Hydrogen as a Decarbonized Fuel

Hydrogen for transportation has an essential role to play in energy diversification strategies. Several studies have shown that it is not possible to electrify the entire transportation sector using only the electric grid. Achieving zero-emission goals through grid charging alone will require adding at least as much generation, transmission and distribution as exists today, but in new load centers – which are likely to be in highly congested areas such as ports, transit agencies, and urban industrial areas.

As a means of storing and transporting clean fuel, hydrogen is an effective alternative to the electric grid. Hydrogen enables greater energy resource diversification, utilizing not only wind and sun but waste streams such as landfill gas and wastewater biogas. Hydrogen as a fuel provides the energy supply stability that have been enjoyed for decades from liquid fuels, allowing for multiple parallel transport pathways through trucking, pipelines and on-site generation, while buffering supply interruptions through gaseous and liquid storage.

Renewable hydrogen is essential to a best-case scenario for clean energy storage and decarbonized transportation on a large scale. When produced from renewable energy, hydrogen is a true zero-emission fuel that also enables grid-balancing and large-scale, long-term energy storage.

Similarities with Compressed Natural Gas

Fuel cell electric buses allow transit agencies that are currently operating CNG buses to gradually transition to a zero-emission fleet mix using a common fuel feedstock (methane) and leveraging the existing infrastructure. Hydrogen is produced on-site using electrolysis delivered via an existing pipeline.

Hydrogen and CNG share many of the same characteristics, making implementation easier:

- Similar piping, compression, gas storage and dispensing systems
- Similar refueling procedures
- Similar leak detection and other safety systems

When sourcing hydrogen fuel, transit operators can submit a tender for companies to supply the hydrogen and even operate and maintain the hydrogen station. There are a variety of companies that will compete for the opportunity, which keeps the price of the fuel down. The price of fuel can be fixed over a period of time, and the transit operator pays in dollars per kilogram. Knowing that a bus typically needs 20-30kg of hydrogen per day facilitates accurate budgeting.

Hydrogen filling stations at transit depots are built to be scalable. A station can simply and cost-effectively increase its capacity from 10-100 or more buses by upgrading the compression and storage equipment and adding dispensers.

Operating a combination of low-emission CNG buses with zero-emission fuel cell electric buses out of a single transit depot is a model that is both economical and scalable to potentially hundreds of buses.

HYDROGEN ENERGY

Properties of Hydrogen

Even though the use of hydrogen to fuel vehicles is relatively new, hydrogen has been used, transported, and stored safely in industrial applications for decades. Heavy-duty vehicles powered by Ballard have now traveled more than 150 million kilometers in a variety of challenging conditions and environments around the world.

The energy in 1kg of hydrogen gas is about the same as the energy in 2.8kg of gasoline. Because hydrogen has a low volumetric energy density, it is stored on-board a vehicle as a compressed gas to achieve the driving range of conventional vehicles.

Hydrogen has the following characteristics:

- Lighter than air, rising and dispersing quickly in air
- Colorless, odorless, tasteless and non-toxic
- Very large flammability range
- Burns as an invisible flame
- Burns rapidly in comparison to other fuels

There are inherent risks that have to be mitigated when handling any flammable gas or liquid, including traditional gasoline. When used in accordance with proper guidelines, hydrogen fuel is safe for public transportation.

Hydrogen Safety

When designing facilities for hydrogen, key considerations are preventing the formation of ignitable concentrations of hydrogen and removing all sources of ignition from the facility.

Using the properties of hydrogen, a safety regime can be set up in a workshop, paying particular attention to the flammability and the low ignition point. The basic principle in the workshop is to respect the fire triangle – which incorporates oxygen, heat and fuel as the three components needed to make a fire.

In a hydrogen vehicle workshop, oxygen – as an ever-present in the air – cannot be removed. However, influence can be taken over the other two sides of the triangle by removing the fuel (hydrogen) or the heat (ignition source). If there are processes in place to ensure that the hydrogen is not released and that ignition sources are removed, two sides of the triangle are removed. In the unlikely event of an accidental hydrogen leak, it will not be ignited.

The cause of any hydrogen leak is down to:

- Wear and tear
- Poor maintenance
- Mishaps during maintenance
- Accidental damage

WEAR & TEAR

Wear and tear should not be an issue if the correct maintenance regime is adhered to. Regular inspection and keeping to the manufacturer's service schedule by qualified technicians will prevent a leak of hydrogen. Parts should be replaced if they are deemed to fail before the next inspection or service interval.

MISHAPS DURING MAINTENANCE

Good processes, training and risk assessments should make sure that mishaps do not occur when a vehicle is being maintained. Secondary sign-off and inspection can also assist in reducing maintenance mishaps.

POOR MAINTENANCE

As with any vehicle, maintenance should only be carried out by trained technicians. Processes must be put in place to ensure that any maintenance is carried out to the highest standards. For any work to be carried out the technician must ensure that the correct tools are available and are in good condition.

ACCIDENTAL DAMAGE

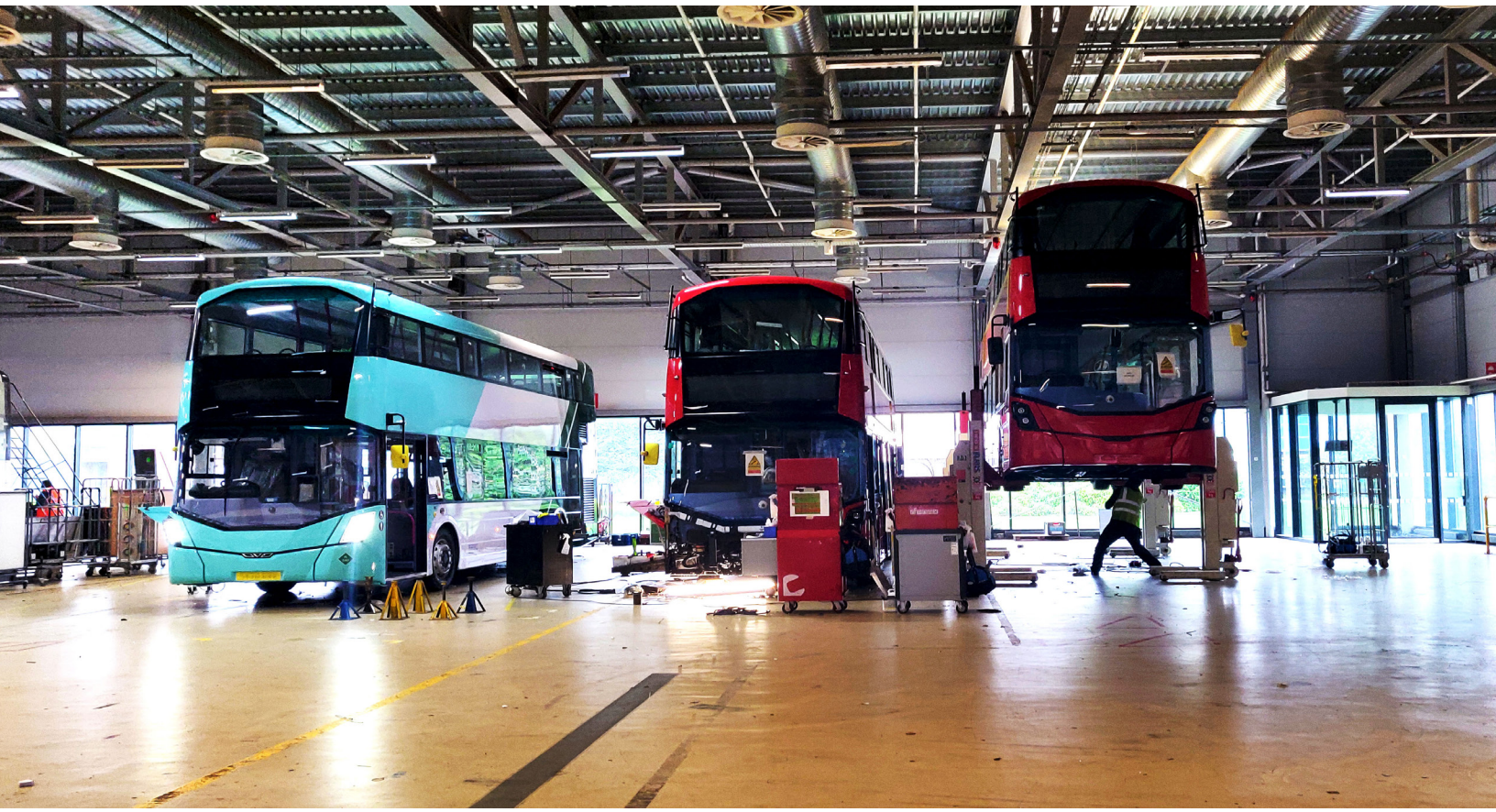
If a fuel cell electric bus is involved in an accident, the integrity of the hydrogen system must be checked by a qualified technician before it is driven again. A small leak may trigger an early warning, to allow a driver to stop and park the vehicle while it is still safe. Collision sensors are designed to activate a "safe shutdown" sequence that locks the high-pressure hydrogen in the tank and isolates the high-voltage components from the system.

SAFETY PRECAUTIONS

When maintaining hydrogen vehicles and keeping the fire triangle in mind, the aim is to not release any hydrogen in the workshop and, if by some chance this does happen, not expose the hydrogen to a heat or ignition source.

To achieve this:

- Adhere to local regulations and health and safety laws
- Understand the properties of hydrogen and how it will react if released inside or outside a building
- Have the correct level of training for technicians and all personnel who will work in the workshop or with the hydrogen vehicle
- Create robust working processes including risk assessment
- Manage and supervise to ensure that correct safe procedures are being carried out
- Make necessary adaptations to the workshop to ensure a safe working area



Hydrogen Facility Requirements

It is recommended that transit agencies initially consult with a reputable safety consultant, professional building contractor, and local authorities to determine the scope of changes required for the facilities to safely operate hydrogen-fueled vehicles. Local regulations and health and safety laws may vary and dictate exactly what adaptions need to be made in the workshop.

To create a safe environment for fuel cell electric buses, existing workshop buildings will require adapting and upgrading. These upgrades are designed to detect a potential hazard, dilute the gas to reduce ignition risk, and then extract the gas for safe re-entry. Anyone with CNG-fueled vehicle experience will be familiar with the types of adaptations required.

FACILITY ROOFLINE

Hydrogen is lighter than air and will rise when released. If this happens in an open environment, it will disperse quickly and will no longer be a hazard. However, inside a workshop facility hydrogen can get trapped and pool in the ceiling area thus potentially creating a flammable hydrogen cloud. If this is ignited, it could cause a detonation or deflagration.

Therefore, it is good practice to have sloping ceilings. This makes it easier to predict where the hydrogen may produce a cloud. Venting can be installed along the roofline to remove the potential of hydrogen in these areas.

WORKING AT HEIGHT

As many components are situated on the roof of a fuel cell electric bus, there may be a requirement for working at height. Therefore, either a platform for working at height or fall arrest equipment needs to be installed in the workshop with appropriate training given to the technicians.

It must also be noted that heavy parts may need to be removed and/or replaced on the roof of the bus, so some form of hoist needs to be available to enable this process to take place.

VENTING OR AIR CHANGES

A provision for venting should be employed, with fans being a popular method used to draw the hydrogen out of the building. Permanent vents at the highest point of the eave can provide a direct route to vent any hydrogen to the atmosphere. A regime of air changes within the building minimizes the potential build-up of any released hydrogen gas.

ELECTRICAL EQUIPMENT

All electrical equipment must be classified for hazardous locations. Heating equipment must be of non-ignition type and away from where hydrogen may pool. Overhead heating is generally not suitable. A grounding system for the fuel cell electric bus must be in place.

Training

Ballard offers extensive training for owners and operators of fuel cell electric buses. The schedule features technical information on the use of hydrogen as a transportation fuel. It covers hydrogen properties, use, and safety – as well as fuel cell technologies, systems, engine design, safety, and maintenance.

In North America, for example, resources and training programs have been made available by the U.S. Department of Energy's Clean Cities organization. Subsequently, industry leaders have developed in-person workshops and online resources that guide how to upgrade maintenance garages for hydrogen. The workshops cover important topics, including gas detection, emergency ventilation, heating, alarm systems, and a review of fuel properties.

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Procedures & Documentation

When producing any processes and documentation for fuel cell electric buses it should be undertaken with a safety-first attitude. It must consider not just how to treat hydrogen safely, but all the other associated hazards such as high voltage and high pressure.

RISK ASSESSMENT

Risk assessment is an ideal way of mitigating against hazards that are in the workshop environment. When maintaining a hydrogen fuel cell vehicle there may be new hazards in the workshop that have not been experienced before. The obvious one is the presence of hydrogen in the vehicle and therefore in the workshop. Hydrogen can be hazardous, but with correct handling, understanding and mitigation following a logical risk assessment process the risks can be controlled.

There are five basic steps to risk assessment:

- Identify hazards
- Assess the risks
- Control the risks
- Record your findings
- Review the controls

It is important to note that a risk assessment is not a static document and is reviewed regularly.

EMERGENCY RESPONSE PROCEDURE

A good risk assessment process and documentation helps create a safe working environment. However, robust processes in place to deal with an incident will prove invaluable and can turn an incident to a manageable occurrence with a less severe consequence.

Safety distances and evacuation procedures should be understood and disseminated to anyone that could be affected. This will require giving this information to any visitors that are on site. It must also be assumed that an incident may happen at any time so all information must be understood at any time even if the hydrogen workshop is not operating.

It is prudent to advise the local emergency services that the depot is now maintaining vehicles with hydrogen on board as a fuel. Making the personnel aware of the potential hazard can enable them to prepare their own response in the event of an emergency. This can save valuable time, preventing injury and damage to property.

SAFETY EQUIPMENT TESTING PROCEDURES

Safety equipment such as a hydrogen detection system are fitted as standard in the workshop. There must be confidence that this will operate when required and that it is measuring accurately.

A calibration regime must be put in place. Regular calibration to the manufacturers recommendations will ensure that the system is working to the correct parameters.

A check of any alarm or venting system must be carried out. This will check that in between any calibration there has not been any malfunction. It can also be useful to carry out an evacuation or have emergency scenario practice to check that the systems put in place are thorough.

If there is any safety equipment is kept in a different location, for instance, if a hydrogen detector is in an emergency kit, it must be ensured that this is always charged up, functional and calibrated within its required period.

MAINTENANCE PROCEDURES

Robust maintenance procedures and processes that are written from the manufacturer's recommendations are vital. Processes should be established so they are carried out in a safe manner, outlining all the correct tools and personal protective equipment (PPE) that is required for the task.

INCIDENT INVESTIGATION PROCEDURES

A rigorous, impartial investigation procedure is required to be set up to investigate any accident, incident or near miss that has taken place in the workshop. If undertaken impartially, valuable lessons can be learned to prevent a repeat incident.

Any actions or recommendations from the investigation should be time-limited and it is likely that some steps must be taken before a process or a tool is used again. Actions should also be allocated to a person and management must oversee to ensure that actions and recommendations are being implemented at the correct time and in full.

In some instances, incidents are reportable to the correct authorities – if this is the case then ensure that this takes place and all statutory requirements are fulfilled.

Case Study – Metrobus, Gatwick, UK

Metrobus – who are a subsidiary of Brighton and Hove Buses, part of the Go-Ahead Group – introduced 20 hydrogen fuel cell electric buses into operational service in Gatwick, UK in 2023. Funding for the project comes from the Clean Hydrogen Partnership's second phase of the Joint Initiative for Hydrogen Vehicles across Europe (JIVE2), with additional support from Gatwick Airport.

The buses operate in full revenue service on Fastway Route 10, which runs between Bewbush and Gatwick Airport, and Fastway Route 20, between Pease Pottage and Horley. Both routes incorporate the strategic location of London Gatwick Airport – the UK's second largest airport with over 40 million passengers per year. Showcasing the commitment to zero-emission, this initial fleet of 20 form part of Metrobus' wider ambition to fully decarbonize by 2035.

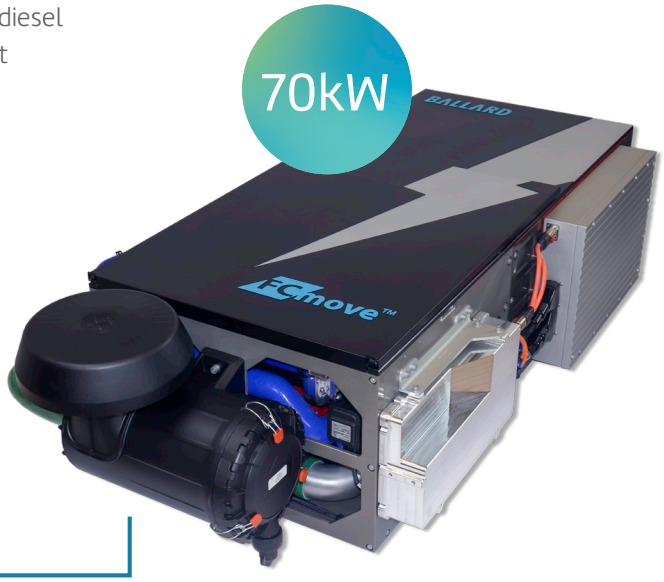
THE BUS

Metrobus selected Wrightbus' Kite Hydroliner, which incorporates Ballard's FCmove®-HD fuel cell engine, that delivers 70kW of power. With a capacity of 37kg of gaseous hydrogen at 350bar, the buses easily fulfil the requirements of the Freeway routes, which demand a range of nearly 600km on a 24-hour service, 365 days a year. The Wrightbus Kite Hydroliner can be used as a drop-in replacement for the diesel buses that were previously used on the routes, with depot processes requiring no alteration to accommodate the zero-emission vehicles.

FUELING

Metrobus have invested in the future. By installing permanent refueling infrastructure – which represents the biggest liquid hydrogen fueling station in Europe – it allows for the potential of servicing the entire Crawley-based fleet of 140 buses with hydrogen.

Up to 5,000kg of hydrogen is delivered in liquid form, which is transported cryogenically at -253C in the storage tank. When needed, the hydrogen is vaporized and compressed to gaseous form for delivery to the bus at 350bar. This can then be delivered to the fuel cell electric buses at one of the depot's two dispensers. Fueling takes a matter of minutes, which is an important factor when operating a 24-hour route. Having the ability to deliver 250kg per hour means that the fuel cell electric bus fleet can be refueled and ready for service whenever required.



FCmove®-HD

MAINTENANCE

An existing maintenance facility has been converted to enable hydrogen fuel cell buses to be serviced and maintained by local technicians, closely supported by Wrightbus. Retaining has taken place, so the technicians originally working on diesel-powered buses can now safely work and carry out both preventative and corrective maintenance. The buses meet Metrobus' standard maintenance requirements that are also in place for diesel, with inspection occurring every 56 days.

Certain adaptations have been made to the workshop with a hydrogen detection system installed on the ceiling of the workshop with processes in place in case of an unexpected release of hydrogen. An initiative air changing scheme is employed to constantly change the air in the workshop – therefore if an unintended leak does occur, the hydrogen would be safely removed by the change of air. Care has been taken to prevent ignition sources as the electrical wiring is intrinsically safe. To enable work to be carried out safely on the hydrogen system, a platform has been installed so that the technicians can work on the roof of the bus.

THE FUTURE

Metrobus are committed to a zero-emission future, to serve the local population with cleaner air, and to do their part to tackle climate change. Due to the success of the JIVE2 project and partnering with Surrey County Council another 34 fuel cell electric buses are scheduled to join the existing fleet soon – making the Metrobus fleet one of the largest in Europe.

Customer Care

Ballard is committed to working with its global partners to provide exceptional support and service. With more than 40 years of industry experience, Ballard has developed a customer care model that has proved its effectiveness in supporting products deployed globally and in large volumes. Ballard works hard to understand customer challenges and anticipate their needs – from purchase to integration and aftersales support.

Effective coordination and cooperation with partner structures is a fundamental component contributing to the long-term success of fuel cell products on the road. Ballard's key objectives here are:

- Ensuring product up-time
- Providing timely and accurate responses to issues
- Transfering maintenance knowledge and expertise to global customer service teams

Ballard is focused on delivering comprehensive customer care and satisfaction to a level of service that positions Ballard as a leader in the fuel cell industry, offering:

- Call Center: Customer care agents provide remote assistance to solve any product issue, providing technical support for customers' mission-critical product applications
- Product Repair: Ballard has a team of product experts and repair technicians ready to solve any issue from dedicated centers based in Canada and Denmark
- On-Site Service: Ballard's flexible working philosophy means technicians, specialized equipment and technology can be brought directly to the customer's site during product installation, site commissioning or product performance troubleshooting
- Spare Parts Logistics: Housing remote parts warehouses at key centers around the world, Ballard's spare parts logistics systems ensure customers receive the parts they require promptly to maintain product operation
- Product Training: Hosted at the company's dedicated training centers in Canada and Europe or at the customer's own facilities, Ballard designs and conducts in-depth training sessions to transfer fuel cell technology knowledge and product operational understanding to customers – ensuring successful product deployment
- Product Performance Monitoring: Remote and on-site monitoring ensures the free flow of data to support ongoing corrective and preventative maintenance

Ballard understands the importance of bus up-time to transit agencies – and so offers a team of deployment specialists in Canada to provide global support and assistance, as well as service technicians based in Europe, China and the U.S. who are on hand to deliver timely, accurate and successful service to global fuel cell electric bus operators.

Conclusion

Hydrogen, if handled correctly, can be as safe or safer than conventional fossil fuels. Today's hydrogen fuel cell technologies are mature in their safety features but must always be treated with respect and care. Fuel cell electric buses are designed and built for safety, and the protocols for safe storage, maintenance and refueling are well developed and understood.

The use of zero-emission, renewable energy sources for public transportation is a contemporary imperative – so unfounded or outdated hydrogen fuel safety concerns should not prevent cities, agencies or organizations from pushing forward with a plan for transition to a clean, renewable energy source.

Transit operators are now making the decision to shift to hydrogen-fueled transit buses in ever greater numbers, so utilizing their knowledge, insight and experience can also help to guide a successful deployment.

It is important to note that regulations covering the safe handling of hydrogen can vary greatly by region. Consulting with local authorities early in the planning process will facilitate the smooth transition to a zero-emission fuel cell electric bus fleet. Ballard has many years of experience in this area and has the resources to assist with this process.

Ballard has the resources to support and is committed to assisting operators, integrators and OEMs in successfully adapting fuel cell technology to their unique needs and requirements. With extensive industry experience that has helped to empower partners around the world to serve customers and meet decarbonization goals, Ballard continues to lead in the fuel cell space and supports collaborators in improving and maintaining their zero-emission solutions.

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